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Gresset

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(54) **METHOD FOR CONFIGURING WIRELESS TRANSMITTER, COMPUTER PROGRAM PRODUCT, STORAGE MEDIUM, AND WIRELESS TRANSMITTER**

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CPC ***H04B 7/0452*** (2013.01); ***H04B 7/0695*** (2013.01); ***H04W 72/046*** (2013.01)

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(Continued)

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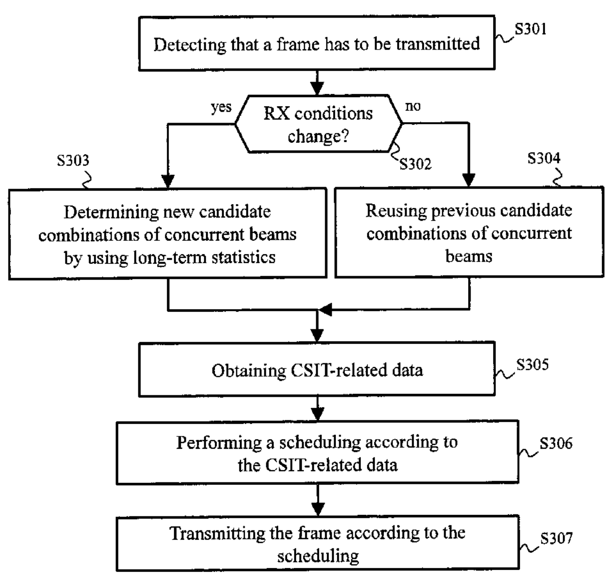
(57) **ABSTRACT**

A wireless transmitter comprises a massive transmit antennas arrangement, a set of modulators, an analog precoder, and a codebook storing candidate predefined beam configurations corresponding to specific phase pattern configurations of the analog precoder. Transmissions of frames by the wireless transmitter are performed by using combinations of concurrent beam configurations stored in the codebook. The wireless transmitter further comprises an online fair scheduler determining which combinations of concurrent beams to be applied so as to take into account a fairness constraint between wireless receivers in view of effective channel conditions, and an offline MU-MIMO fair scheduler implementing a first configuration phase in which candidate combinations of concurrent beams are determined by using long-term statistics, and the online fair scheduler implements a second configuration phase in the combinations of concurrent beams to be applied are selected among the candidate combinations of concurrent beams determined by the offline MU-MIMO fair scheduler.

7 Claims, 7 Drawing Sheets



(51) **Int. Cl.**
H04B 7/06 (2006.01)
H04W 72/04 (2009.01)

(58) **Field of Classification Search**
USPC 375/267
See application file for complete search history.

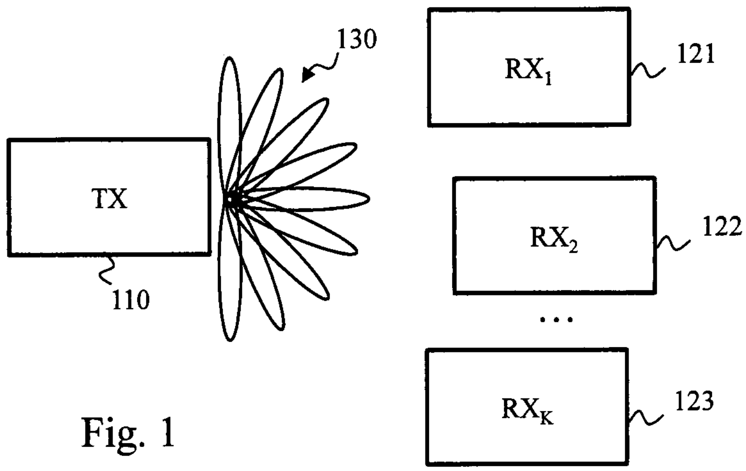

130
RX1
121
TX
RX2
122
110
...
RXK
123

Fig. 1

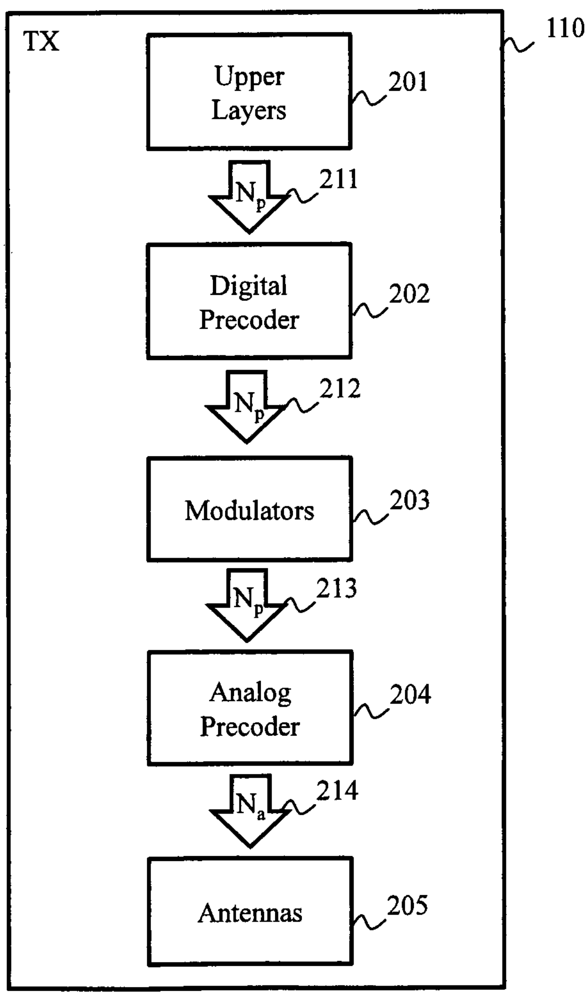

TX
110
Upper Layers
201
Np
211
Digital Precoder
202
Np
212
Modulators
203
Np
213
Analog Precoder
204
Na
214
Antennas
205

Fig. 2

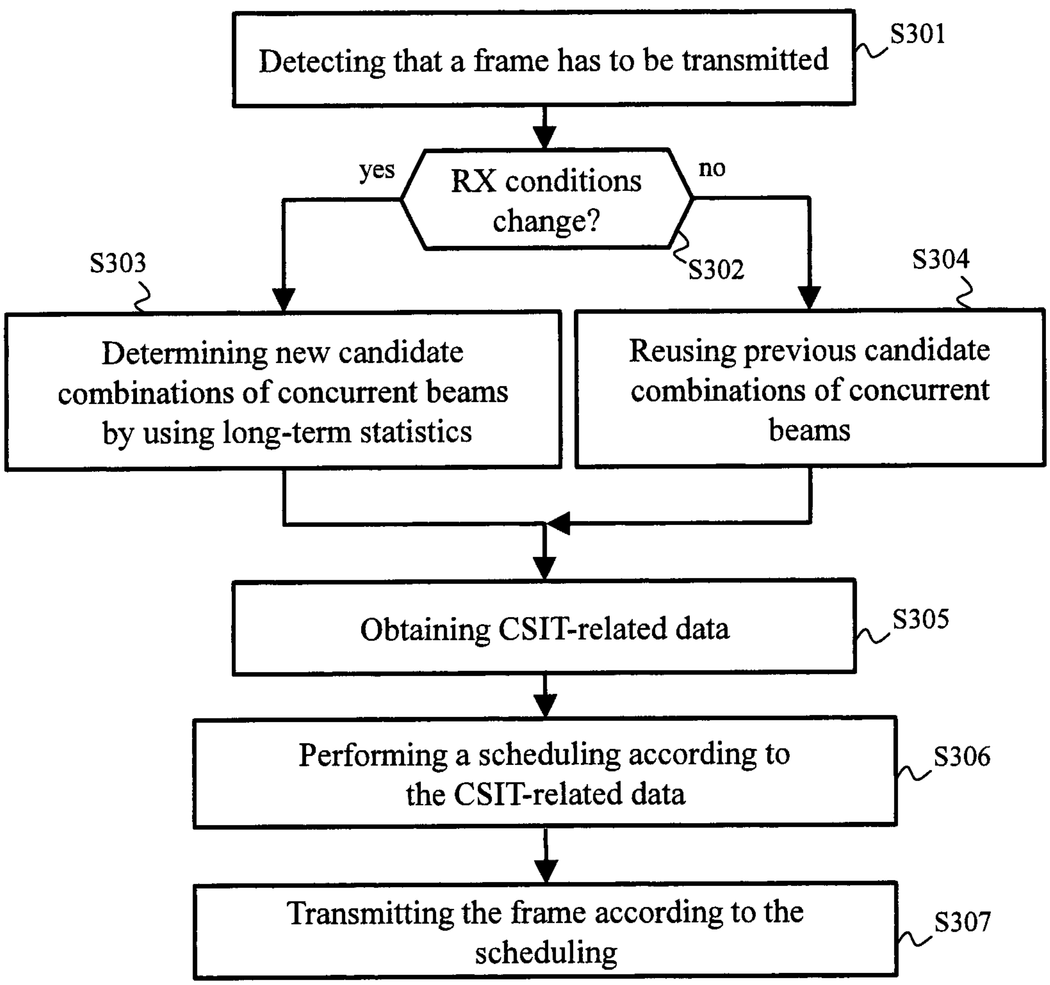

Detecting that a frame has to be transmitted
S301
RX conditions change?
yes
no
S302
S303
Determining new candidate combinations of concurrent beams by using long-term statistics
S304
Reusing previous candidate combinations of concurrent beams
Obtaining CSIT-related data
S305
Performing a scheduling according to the CSIT-related data
S306
Transmitting the frame according to the scheduling
S307

Fig. 3

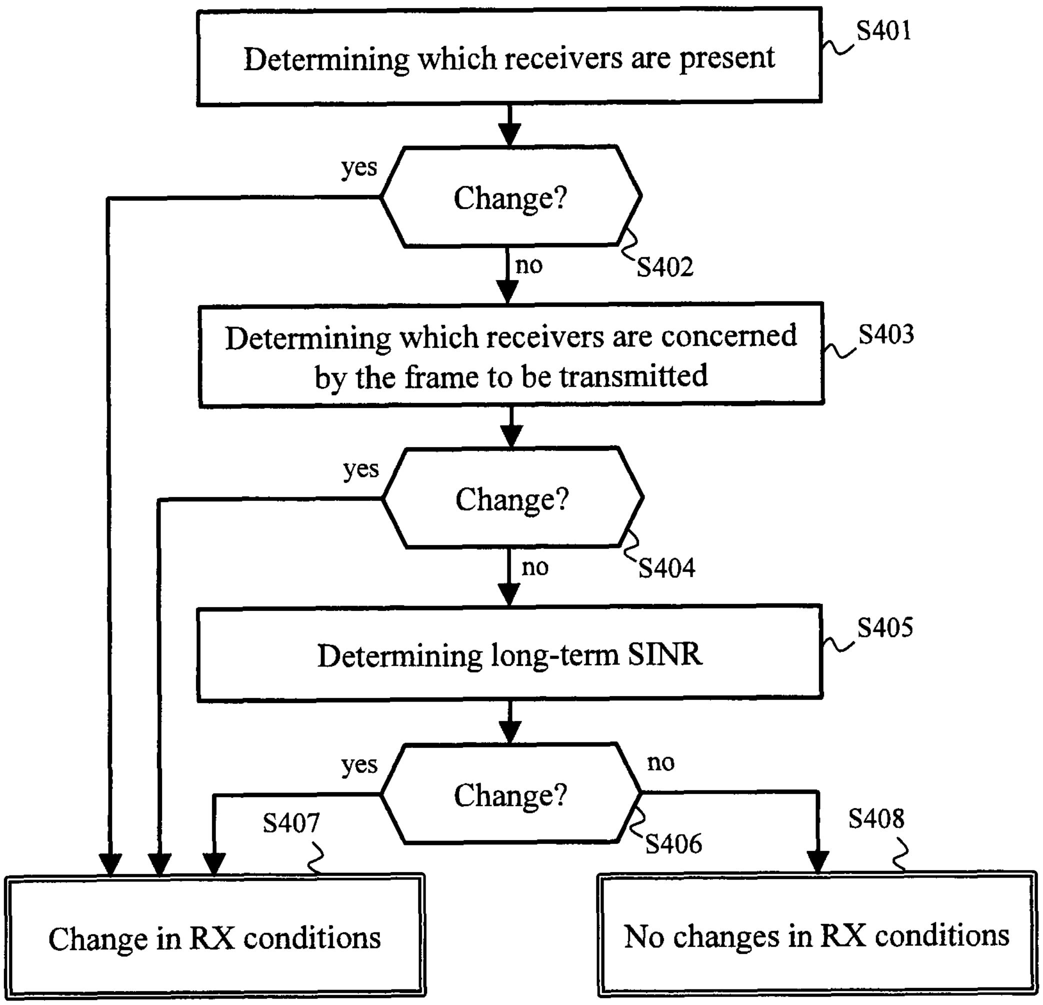

S401
Determining which receivers are present
Change?
yes
no
S402
S403
Determining which receivers are concerned by the frame to be transmitted
Change?
yes
no
S404
S405
Determining long-term SINR
Change?
yes
no
S406
S407
S408
Change in RX conditions
No changes in RX conditions

Fig. 4

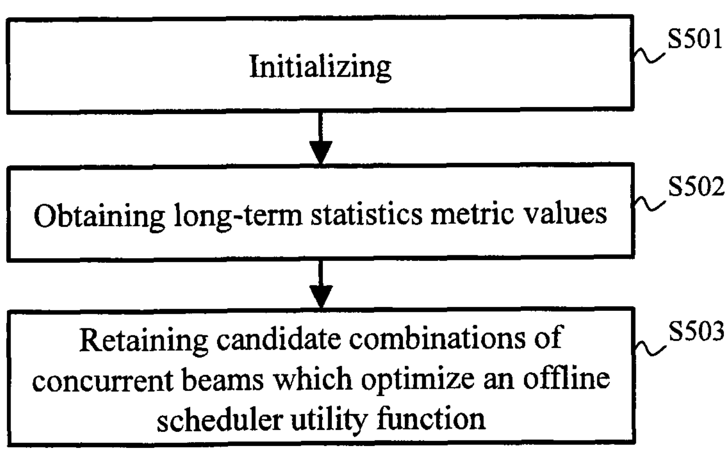

S501
Initializing
S502
Obtaining long-term statistics metric values
S503
Retaining candidate combinations of concurrent beams which optimize an offline scheduler utility function

Fig. 5

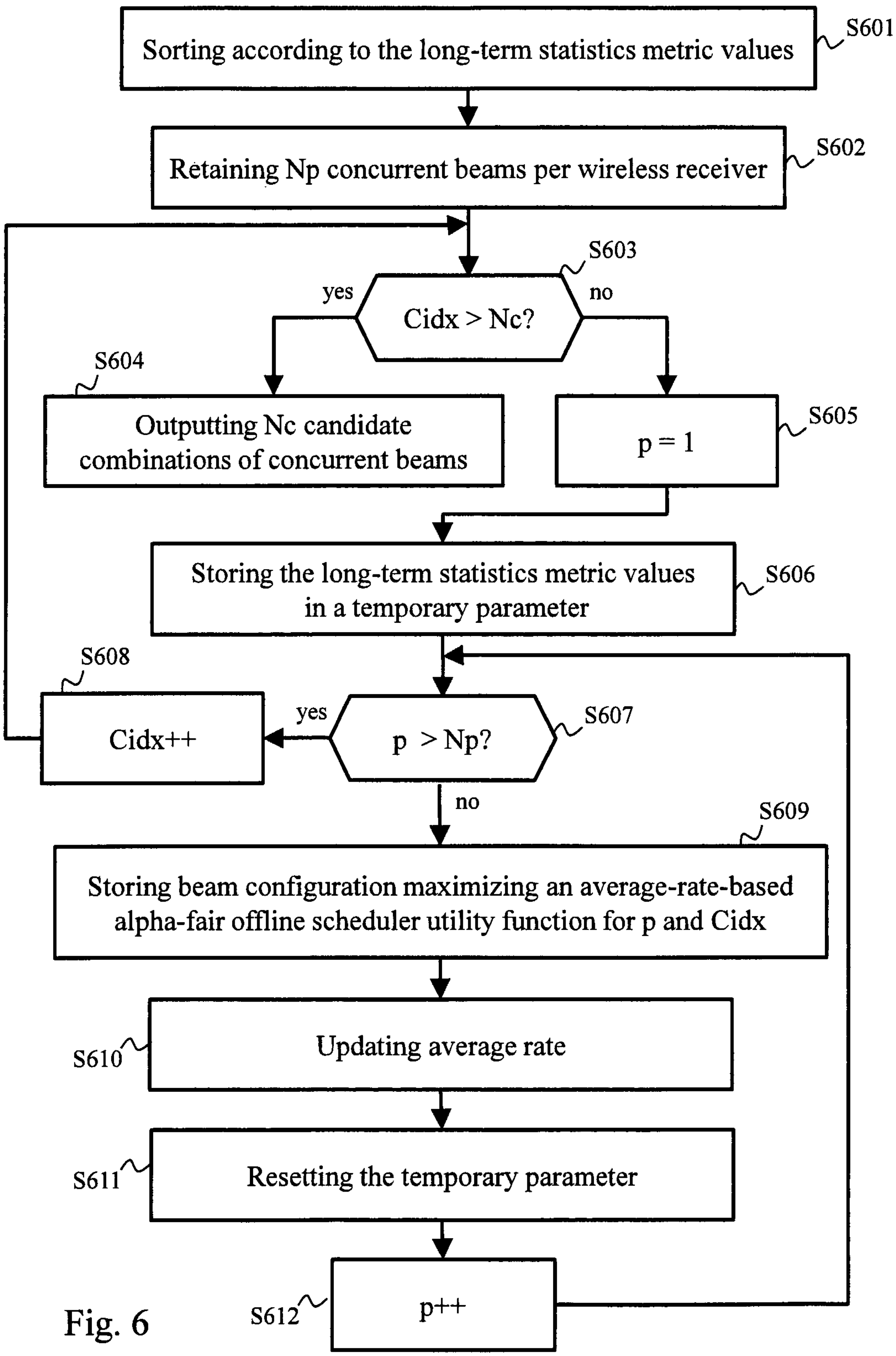

Sorting according to the long-term statistics metric values
S601
Retaining Np concurrent beams per wireless receiver
S602
S603
yes
Cidx > Nc?
no
S604
Outputting Nc candidate combinations of concurrent beams
p = 1
S605
Storing the long-term statistics metric values in a temporary parameter
S606
S608
Cidx++
yes
p > Np?
S607
no
S609
Storing beam configuration maximizing an average-rate-based alpha-fair offline scheduler utility function for p and Cidx
S610
Updating average rate
S611
Resetting the temporary parameter
S612
p++

Fig. 6

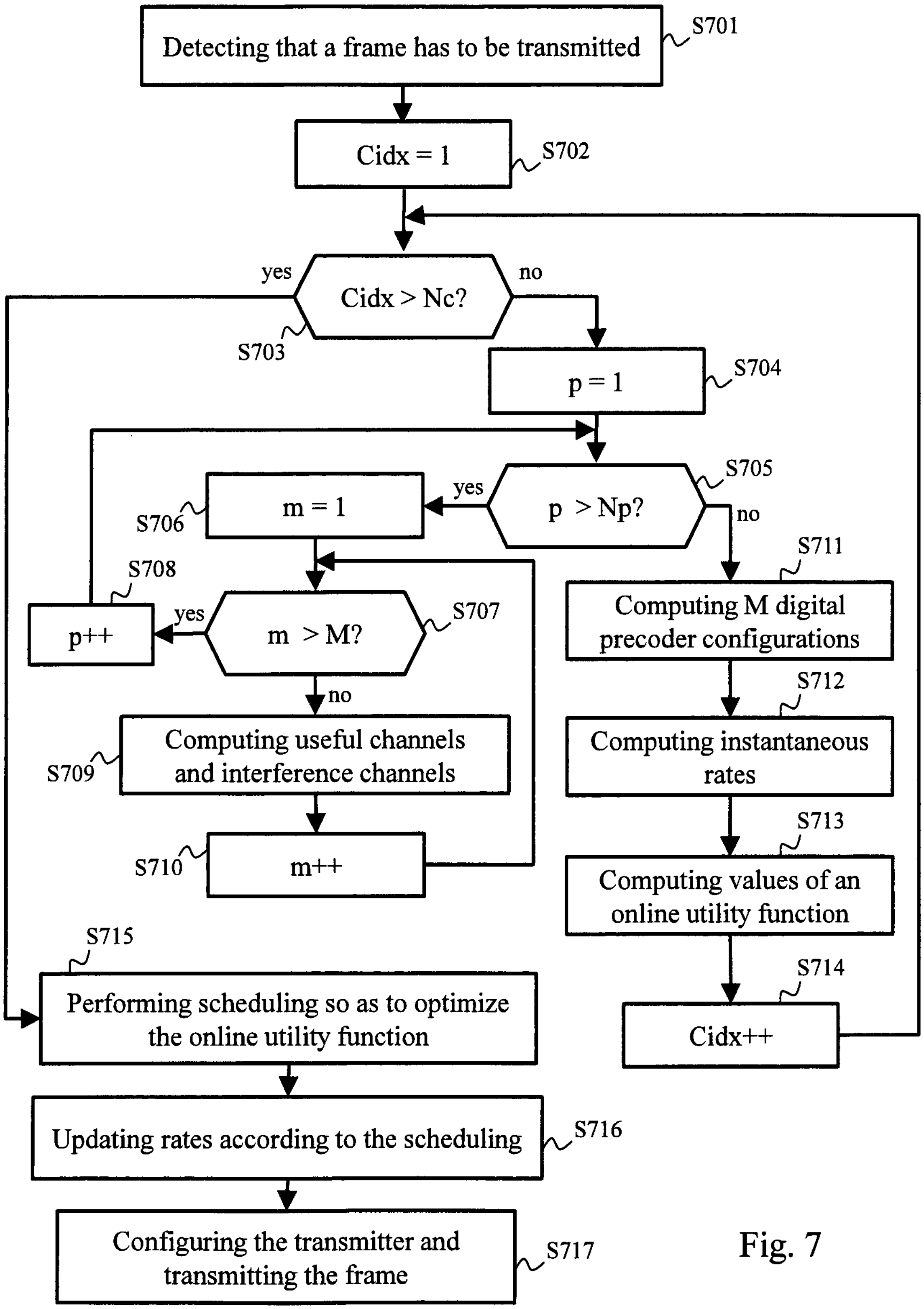

Detecting that a frame has to be transmitted
S701
Cidx = 1
S702
Cidx > Nc?
yes
no
S703
p = 1
S704
p > Np?
yes
no
S705
m = 1
S706
m > M?
yes
no
S707
p++
S708
Computing useful channels and interference channels
S709
m++
S710
Computing M digital precoder configurations
S711
Computing instantaneous rates
S712
Computing values of an online utility function
S713
Cidx++
S714
Performing scheduling so as to optimize the online utility function
S715
Updating rates according to the scheduling
S716
Configuring the transmitter and transmitting the frame
S717

Fig. 7

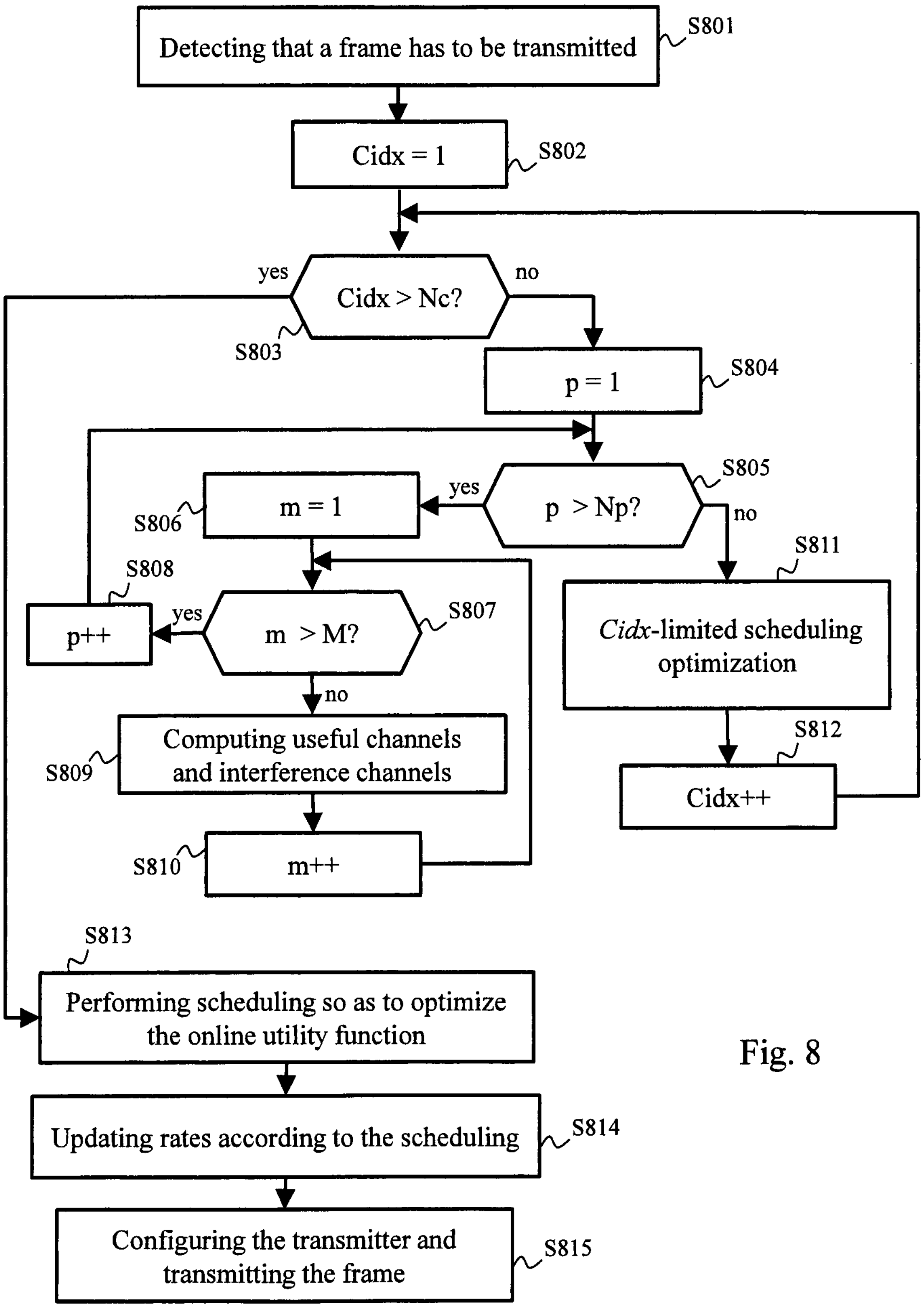

Detecting that a frame has to be transmitted
S801
Cidx = 1
S802
yes
Cidx > Nc?
no
S803
p = 1
S804
S805
m = 1
yes
p > Np?
no
S806
S811
S808
S807
p++
yes
m > M?
Cidx-limited scheduling optimization
no
Computing useful channels and interference channels
S809
S812
Cidx++
S810
m++
S813
Performing scheduling so as to optimize the online utility function
Updating rates according to the scheduling
S814
Configuring the transmitter and transmitting the frame
S815

Fig. 8

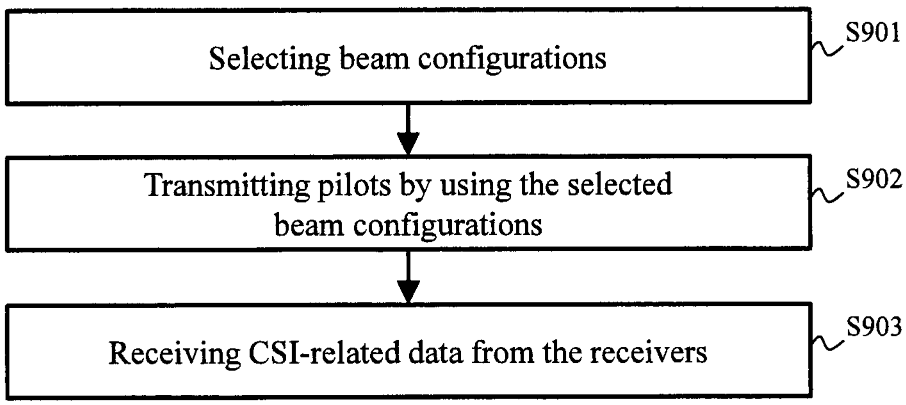

Selecting beam configurations
S901
Transmitting pilots by using the selected beam configurations
S902
Receiving CSI-related data from the receivers
S903

Fig. 9

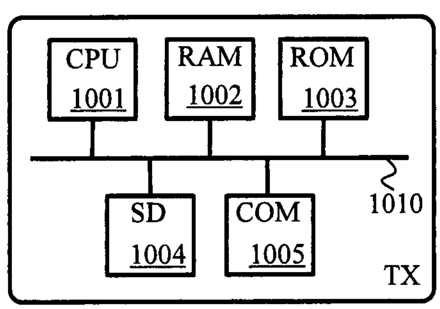

CPU 1001
RAM 1002
ROM 1003
1010
SD 1004
COM 1005
TX

Fig. 10

METHOD FOR CONFIGURING WIRELESS TRANSMITTER, COMPUTER PROGRAM PRODUCT, STORAGE MEDIUM, AND WIRELESS TRANSMITTER

TECHNICAL FIELD

The present invention generally relates to a method for configuring a MU-MIMO (Multi-User-Multiple Inputs Multiple Outputs) wireless transmitter for transmitting a frame toward a plurality of MIMO wireless receivers, wherein the wireless transmitter transmits the frame using an analog precoder connected to a massive transmit antennas arrangement. The invention is more particularly suitable for millimeter wave wireless transmissions.

BACKGROUND ART

Analog precoders mix modulated analog signals onto inputs of a massive transmit antennas arrangement. For example, Na=4096 transmit antennas are used. Mixing usually consists in duplicating each input modulated analog signal into Na copies thereof, in performing a phase rotation of each signal copy, routing each phase-rotated signal copy to one transmit antenna input, and summing all rotated signal copies arriving at each transmit antenna input. The phases applied are typically different. Thus, an equivalent beam resulting from signal duplication and phases rotation to the transmit antennas is associated with each modulated analog signal. Thus, considering Np modulated analog signals, Np equivalent beams are observed between the Np inputs of the analog precoder and a wireless receiver.

The phase rotations performed by the analog precoder are controllable. A codebook CB of Nb=Na phase patterns can be used. For example, a DFT (Discrete Fourier Transform) matrix of size equal to Na*Na is used to create the codebook CB of Na equivalent beams, defined by the columns of the DFT matrix. A subset of Np≤Na beams from the codebook CB can be selected and used concurrently for transmitting a frame, thus creating a combination of concurrent beams. And if phases switching is fast enough, the combination of concurrent beams can be changed from one frame to another without significant overhead on overall throughput. It means that the same combination of concurrent beams is used for transmitting one or more whole frames, i.e. for all time and frequency resources used to transmit said one or more whole frames.

Usually, the configurations of the combination of concurrent beams are selected so as to maximize received power or SINR (Signal-to-Interference-plus-Noise Ratio) toward wireless receivers. A digital precoder, placed upstream the analog precoder, can then be computed in order to mitigate interference observed between the concurrent beams in use.

In wireless transmissions, time and frequency resources allocation to the wireless receivers is performed by taking account of an amount of data to be delivered to each wireless receiver (which depends on application layer requirements), further of a quality of a wireless channel from the wireless transmitter to each wireless receiver (which depends on position of each wireless receiver with respect to the wireless transmitter and on channel realization toward each wireless receiver), and further by optimizing a proportional fairness metric between the wireless receivers. Thus, the wireless transmitter (such as cellular telecommunication network base station) has to solve a scheduling optimization problem that takes into account several aspects among which:

which wireless receivers should be grouped together for performing a MU-MIMO transmission, and on which time and frequency resource; and

how the analog precoder, and potentially the upstream digital precoder (if any), should be configured for each group of wireless receivers.

When the quantity of wireless receivers to be grouped together is small enough (e.g. 2), low complexity solutions can be envisaged in order to solve the scheduling optimization problem while meeting a fairness constraint. However, when increasing the quantity of wireless receivers to be simultaneously served and when considering flexibility brought by using concurrent analog beams, the prior art solutions summarized above become intractable.

It is thus desirable to overcome the aforementioned drawbacks of the prior art. It is more particularly desirable to provide a solution that reduces complexity when scheduling data transmissions toward wireless receivers in a MU-MIMO context.

It is more particularly desirable to provide a solution that is simple and cost-effective.

SUMMARY OF INVENTION

To that end, the present invention concerns a method for configuring a wireless transmitter comprising a massive transmit antennas arrangement, a set of Modulators and an analog precoder mixing modulated analog signals output by the set of modulators onto respective inputs of the massive transmit antennas arrangement, the wireless transmitter further comprising a codebook storing candidate predefined beam configurations corresponding to a specific phase pattern configuration of the analog precoder, transmissions of frames by the wireless transmitter being performed onto respective time and frequency resources by using combinations of concurrent beam configurations among the candidate predefined beam configurations stored in the codebook so as to perform MU-MIMO transmissions toward wireless receivers, the method being implemented by the wireless transmitter. In addition, the wireless transmitter further comprises an online fair scheduler determining which combinations of concurrent beams to be applied onto the time and frequency resources so as to take into account a fairness constraint between the wireless receivers in view of effective channel conditions toward the wireless receivers, wherein the wireless transmitter performs a frame transmission onto the time and frequency resources by configuring the analog precoder according to the combinations of concurrent beams determined by the online fair scheduler. The method is such that the wireless transmitter further comprises an offline MU-MIMO fair scheduler implementing a first configuration phase in which the offline MU-MIMO fair scheduler determines candidate combinations of concurrent beams by using long-term statistics associated to performance of transmissions from the wireless transmitter toward the wireless receivers and by taking into account the fairness constraint between the wireless receivers, and the method is such that the online fair scheduler implements a second configuration phase in which the online MU-MIMO fair scheduler selects the combinations of concurrent beams to be applied onto the time and frequency resources among the candidate combinations of concurrent beams determined by the offline MU-MIMO fair scheduler during the first configuration phase. Thus, thanks to the first configuration phase performed by the offline MU-MIMO fair scheduler using the long-term statistics, complexity of effective scheduling operations performed by the online MU-MIMO fair scheduler is reduced since by the online MU-MIMO fair scheduler has only to focus on a reduced set of candidate combinations of concurrent beams.

According to a particular embodiment, the wireless transmitter reinitiates the first configuration phase when receive conditions of the MU-MIMO transmissions have changed compared with a preceding frame transmission. Thus, the candidate combinations of concurrent beams are adequate over time.

According to a particular embodiment, the receive conditions of the MU-MIMO transmissions have changed compared with a preceding frame transmission when at least one of the following conditions is faced: when the long-term statistics of at least one wireless receiver have changed since the preceding frame transmission; when the wireless transmitter has not enough data anymore to be transmitted to at least one wireless receiver since the preceding frame transmission; when the wireless transmitter has received new data to be transmitted to at least one wireless receiver for which there was precedingly not enough data to be transmitted thereto for the preceding frame transmission; when there is a change, since the preceding frame transmission, in the wireless receivers that are active among all the wireless receivers of a transmission system to which the wireless transmitter belongs; and when there is a change, since the preceding frame transmission, in the wireless receivers presence in the transmission system. Thus, adequation of the candidate combinations of concurrent beams over time is reinforced.

According to a particular embodiment: the offline MU-MIMO fair scheduler retains, as candidate combinations of concurrent beams, the combinations of concurrent beams which optimize a first utility function; and the online MU-MIMO fair scheduler retains, as combinations of concurrent beams to be effectively used for transmission onto the time and frequency resources, the combinations of concurrent beams which optimize a second utility function. Moreover, the first utility function and the second utility function diverge in that the first utility function uses the long-term statistics metric values to anticipate potential scheduling result, whereas the second utility function uses the effective channel conditions toward the wireless receivers to decide scheduling to be effectively applied. Thus, relevance of the candidate combinations of concurrent beams can be easily achieved.

According to a particular embodiment, the wireless receivers supposed to be targeted with each one of the candidate combinations of concurrent beams are defined by the offline MU-MIMO fair scheduler during the first configuration phase. Thus, complexity of effective scheduling operations performed by the online MU-MIMO fair scheduler is reduced since wireless receivers grouping is performed offline.

According to a particular embodiment, the wireless receivers effectively addressed with any one of the candidate combinations of concurrent beams are defined by the online MU-MIMO fair scheduler during the second configuration phase. Thus, the online MU-MIMO fair scheduler is able to modify wireless receivers grouping that is inherently performed offline during the first configuration phase.

According to a particular embodiment, the wireless transmitter further comprises a digital precoder placed upstream the set of modulators, and the online MU-MIMO fair scheduler determines and further applies configurations of the digital precoder during the second configuration phase, namely one configuration of the digital precoder for each one of the time and frequency resources. Thus, inter-receiver interference mitigation is achieved on a per time and frequency resource basis.

According to a particular embodiment, the wireless transmitter determines the union of the beam configurations appearing in the candidate combinations of concurrent beams and requests the wireless receivers to feedback Channel State Information (CSI) data related to said beam configurations of the union so as to determine the effective channel conditions toward the wireless receivers. Thus, CSI-feedback overhead is limited.

The present invention also concerns a computer program that can be downloaded from a communication network and/or stored on a non-transitory information storage medium that can be read by a processing device such as a microprocessor. This computer program comprises instructions for causing implementation of the aforementioned method, when said program is run by the processing device. The present invention also concerns a non-transitory information storage medium, storing such a computer program.

The present invention also concerns a wireless transmitter comprising a massive transmit antennas arrangement, a set of modulators and an analog precoder mixing modulated analog signals output by the set of modulators onto respective inputs of the massive transmit antennas arrangement, the wireless transmitter further comprising a codebook storing candidate predefined beam configurations corresponding to a specific phase pattern configuration of the analog precoder, transmissions of frames by the wireless transmitter being performed onto respective time and frequency resources by using combinations of concurrent beam configurations among the candidate predefined beam configurations stored in the codebook so as to perform Multi-User Multiple-Inputs Multiple-Outputs MU-MIMO transmissions toward wireless receivers. In addition, the wireless transmitter further comprises an online fair scheduler determining which combinations of concurrent beams to be applied onto the time and frequency resources so as to take into account a fairness constraint between the wireless receivers in view of effective channel conditions toward the wireless receivers, wherein the wireless transmitter further comprises means for performing a frame transmission onto the time and frequency resources by configuring the analog precoder according to the combinations of concurrent beams determined by the online fair scheduler. Moreover, the wireless transmitter further comprises an offline MU-MIMO fair scheduler implementing a first configuration phase in which the offline MU-MIMO fair scheduler is configured to determine candidate combinations of concurrent beams by using long-term statistics associated to performance of transmissions from the wireless transmitter toward the wireless receivers and by taking into account the fairness constraint between the wireless receivers, and the online fair scheduler implements a second configuration phase in which the online MU-MIMO fair scheduler is configured to select the combinations of concurrent beams to be applied onto the time and frequency resources among the candidate combinations of concurrent beams determined by the offline MU-MIMO fair scheduler during the first configuration phase.

The characteristics of the invention will emerge more clearly from a reading of the following description of at least one example of embodiment, said description being produced with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** schematically represents a transmission system in which the present invention may be implemented.

FIG. **2** schematically represents a wireless transmitter of the transmission system.

FIG. **3** schematically represents an algorithm for configuring the wireless transmitter for transmitting a frame toward a plurality of wireless receivers.

FIG. **4** schematically represents an algorithm for deciding whether candidate combinations of concurrent beams have to be updated for transmitting the frame toward the plurality of wireless receivers, in a particular embodiment.

FIG. **5** schematically represents an algorithm for determining the candidate combinations of concurrent beams which can be applied for transmitting the frame toward the plurality of wireless receivers.

FIG. **6** schematically represents an algorithm for determining the candidate combinations of concurrent beams which can be applied for transmitting the frame toward the plurality of wireless receivers, in a particular embodiment.

FIG. **7** schematically represents an algorithm for performing scheduling and transmitting the frame toward the plurality of wireless receivers, in a first scheduling particular embodiment.

FIG. **8** schematically represents an algorithm for performing scheduling and transmitting the frame toward the plurality of wireless receivers, in a second scheduling particular embodiment.

FIG. **9** schematically represents an algorithm for collecting channels observations.

FIG. **10** schematically represents an example hardware architecture of the wireless transmitter.

DESCRIPTION OF EMBODIMENTS

FIG. **1** schematically represents a transmission system in which the present invention may be implemented. The transmission system comprises a wireless transmitter TX **110** and a plurality of Ktot (Ktot>1) wireless receivers RX_1 **121**, RX_2 **122**, . . . , RX_{Ktot} **123** toward which the transmitter TX **110** transmits frames. The wireless transmitter TX **110** uses beamforming **130**, which is a signal processing technique used with transmit antennas arrays for directional signal transmission in such a way that signals in particular transmission directions experience constructive interference while signals in other transmission directions experience destructive interference. The wireless transmitter TX **110** is for example a base station and the wireless receivers RX_1 **121**, RX_2 **122**, . . . , RX_{Ktot} **123** are mobile terminals.

To do so, as schematically depicted in FIG. **2**, the wireless transmitter TX **110** comprises a massive transmit antennas arrangement **205**, for example consisting of an array of Na=2048 or 4096 transmit antennas. The wireless transmitter TX **110** further comprises an analog precoder **204** and a set of Np modulators **203**. The wireless transmitter TX **110** optionally further comprises a digital precoder **202**.

Na analog signals **214** are input to the massive transmit antennas arrangement **205** from the analog precoder **204**. The analog precoder **204** mixes Np modulated analog signals **213** onto the Na inputs of the massive transmit antennas arrangement **205**. The analog precoder **204** duplicates each one of the Np modulated analog signals **213** into Na copies thereof, performs a phase rotation of each signal copy, routes each phase-rotated signal copy to one transmit antenna input, and sums all rotated signal copies arriving at each transmit antenna input, thus generating Np equivalent beams (one beam for each one of the Np modulated analog signals **213**).

The Np modulated analog signals **213** are generated by the set of Np modulators **203** from respective Np digital signals **212**. Each modulator comprises a baseband unit, adapted for example to generate an OFDM (Orthogonal Frequency Division Multiplex) baseband signal and a radio frequency circuit that transposes the baseband signal around a carrier frequency. The input of a modulator **203** is typically a set of symbols, each symbol being associated to one time and frequency resource defined by the baseband signal. For example, when considering an OFDM baseband signal, the time and frequency resources are defined by the subcarriers of the OFDM modulation during a predefined time slot.

The digital precoder **202** is placed upstream the analog precoder **204**, and more particularly upstream the set of Np modulators **203**. The digital precoder **202** spatially mixes Np symbols **211** addressed to Np≤Ktot co-scheduled wireless receivers among the Ktot wireless receivers RX_1 **121**, RX_2 **122**, . . . , RX_{Ktot} **123**, so as to generate the aforementioned Np digital signals **212**. The Np symbols **211** are provided by upper layers **201** within a transmission protocol stack of the wireless transmitter TX **110**. For example, one of the symbol targets a given wireless receiver, and is a QAM (Quadrature Amplitude Modulation) symbol carrying coded bits belonging to a codeword of an error correcting code associated with an information word, said information word resulting from a segmentation of data present in a buffer associated with said wireless receiver and stored in the wireless transmitter TX **110**. The integer Np thus represents a quantity of simultaneous spatial streams, which is, for simplicity purpose, assumed equal to the quantity of wireless receivers simultaneously (i.e. at the same time) served by the wireless transmitter TX **110**. In other words, when plural spatial streams are intended to be delivered to a single wireless receiver, it is equivalent as delivering said spatial streams to distinct wireless receivers with identical transmission channel characteristics. Moreover, since the Np spatial streams can be attributed to different wireless receivers from one frame to another, the wireless transmitter TX **110** keeps track of a mapping between the Np spatial streams for each frame and the wireless receivers targeted by said spatial streams for said frame.

When the digital precoder **202** is omitted, the Np symbols **211** are directly input to the set of Np modulators **203**.

It can be noted that the generated beams are wideband, which means that equivalent antenna gain observed by any wireless receiver is identical over the whole transmission band. Thus, the configuration of the analog precoder **204** cannot be changed across the frequency domain, contrary to the configuration of the digital precoder **202**, which can be computed independently from one subcarrier (or group of subcarriers) to another in a multicarrier transmission system (e.g. OFDM) context.

FIG. **3** schematically represents an algorithm for configuring the wireless transmitter TX **110** for transmitting a frame toward Np wireless receivers.

In a step **S301**, the wireless transmitter TX **110** detects that data has to be transmitted toward at least one of the Ktot wireless receivers. Said data has to be included in a frame. The frame has to be transmitted on several time and frequency resources, which are usually called Physical Resource Blocks (PRB) in 3GPP LTE-based systems. For example, each time and frequency resource contains 12 contiguous subcarriers across 7 contiguous OFDM symbols in a given time slot, and a 20 MHz wideband contains 100 PRBs in the frequency domain. It is considered herein that one frame is transmitted over M time and frequency resources, which have to be appropriately selected by the wireless transmitter TX **110** as described hereafter. As a result, it is considered that data addressed to Np different wireless receivers can be spatially multiplexed on each time and frequency resource, and that the wireless receivers served on two different time and frequency resources might be different.

In a step S**302**, the wireless transmitter TX **110** checks whether or not receive conditions have changed compared with a preceding frame transmission. In other words, the wireless transmitter TX **110** checks whether the situation of at least one of the wireless receivers of the transmission system has changed. The situation of at least one wireless receiver is said to have changed when long-term statistics, considered herein to determine candidate combinations of concurrent beams which can be applied for transmitting a frame (i.e. among which selection has to be made), have changed since the last frame transmission. In another case, the situation of at least one wireless receiver is said to have changed when the wireless transmitter TX **110** has not enough data anymore to be transmitted thereto (getting below a predefined threshold), or when the wireless transmitter TX **110** has received new data to be transmitted thereto whereas there was precedingly not enough data to be transmitted thereto (getting above the predefined threshold). A particular embodiment for determining whether receive conditions have changed compared with said preceding frame transmission is detailed hereafter with respect to FIG. **4**. In a particular embodiment, the wireless transmitter TX **110** is able to determine which wireless receivers ARX_1, ARX_2, . . . , ARX_K are active in the transmission system (a change in the wireless receivers active in the transmission system can be considered as a change in the receive conditions) among the Ktot wireless receivers.

When the receive conditions have changed, a step S**303** is performed; otherwise, a step S**304** is performed.

In the step S**303**, the wireless transmitter TX **110** determines new candidate combinations of concurrent beams which can be applied for transmitting the frame. The candidate combinations of concurrent beams are obtained by an offline MU-MIMO fair scheduler using long-term statistics associated to the wireless receivers to be served, so as to take into account a fairness constraint between the wireless receivers. This represents a first configuration phase.

The long-term statistics are representative of statistical performance of wireless transmissions from the wireless transmitter TX **110** to the K active wireless receivers ARX_1, ARX_2, . . . , ARX_K over time. The long-term statistics are in particular SINR and covariance matrices resulting from observations made by the K active wireless receiver ARX_1, ARX_2, . . . , ARX_K over time during transmissions performed by the wireless transmitter TX **110**. This approach allows selecting a subset of predefined possible combinations of concurrent beams which actually fits with the transmission channel situations statistically experienced by the active wireless receivers ARX_1, ARX_2, . . . , ARX_K. However, this does not accurately take into account channel realization and capability of the digital precoder **202** (when present) to mitigate inter-receiver interference. This is performed in a second configuration phase implemented by an online MU-MIMO fair scheduler, as described hereafter.

It has to be noted that the more the transmission channel is stable with respect to fading realization, the closer the transmission system effective performance to the performance predicted by the long-term statistics. Combination of millimeter waveband and massive antennas MIMO approach provides a quite good stability to fading realization (thanks to narrow concurrent beams and multiple antennas). Particular embodiments for determining appropriate candidate combinations of concurrent beams from the long-term statistics are detailed hereafter with respect to FIGS. **5** and **6**. Then a step S**305** is performed.

In the step S**304**, the wireless transmitter TX **110** reuses the candidate combinations of concurrent beams used for said preceding frame transmission, since the receive conditions remain substantially the same and no impact has been observed on the long-term statistics. Then the step S**305** is performed.

In the step S**305**, the wireless transmitter TX **110** obtain CSIT (Channel State Information at Transmitter)-related data. The CSIT-related data are derived from CSI (Channel State Information) fed back by the active wireless receivers ARX_1, ARX_2, . . . , ARX_K to the transmitter TX **110**. The CSIT-related data provide a representation of actual transmission channels between the wireless transmitter TX **110** and the Np wireless receivers to be served. Building CSIT-related data from CSI fed back by wireless receivers is widely addressed in the prior art. A particular embodiment for gathering CSI is detailed hereafter with respect to FIG. **9**.

In a step S**306**, the wireless transmitter TX **110** performs a scheduling according to the CSIT-related data obtained in the step S**305** and according to the candidate combinations of concurrent beams resulting from the step S**303** or S**304**. The wireless transmitter TX **110** can compute, for each time and frequency resource to be used to transmit the frame, a multi-user scheduling metric value for each one of said candidate combinations of concurrent beams, and then select the candidate combination of concurrent beams to be effectively applied for said time and frequency resource, as well as group of addressed wireless receivers, and optionally digital precoder configuration, so as to optimize the multi-user scheduling metric. To do so, the wireless transmitter TX **110** implements an online MU-MIMO fair scheduler. Particular embodiments for performing adequate scheduling are detailed hereafter with respect to FIGS. **7** and **8**.

In a step S**307**, the wireless transmitter TX **110** builds the frame and transmits, on the time and frequency resources that were identified to be used to transmit the frame, the built frame according to the combination of concurrent beams, group of targeted wireless receivers, and optionally digital precoder configuration, which result from the scheduling performed in the step S**306**.

It has to be noted that, in the case where more time and frequency resources for transmitting the frame are available compared with the quantity of data to be effectively transferred, redundancy can be introduced so as to fill up said time and frequency resources.

FIG. **4** schematically represents an algorithm for deciding whether candidate combinations of concurrent beams have to be updated for transmitting a frame toward Np wireless receivers, in a particular embodiment.

In a step S**401**, the wireless transmitter TX **110** determines which wireless receivers are present in the transmission system. Indeed, a wireless receiver may have been turned on or off, or may have experienced a handover toward another cell.

In a step S**402**, the wireless transmitter TX **110** checks whether or not there is a change in the wireless receivers presence in the transmission system compared with a preceding frame transmission. When the wireless receivers in the transmission system are the same as previously, a step S**403** is performed; otherwise, a step S**407** is performed.

In a step S**403**, the wireless transmitter TX **110** determines which K active wireless receivers ARX_1, ARX_2, . . . , ARX_K among the Ktot wireless receivers are concerned by the frame to be transmitted. In a particular embodiment, activity of each wireless receiver is monitored. When a wireless receiver has activity below a predefined threshold, the wireless transmitter TX **110** may consider that said wireless receiver is not concerned by the frame to be transmitted. For example, such activity monitoring is implemented through data buffers filing rate monitoring. At least one data buffer in the wireless transmitter TX **110** is associated with each wireless receiver RX_1 **121**, RX_2 **122**, . . . , RX_{Ktot} **123**, for instance at application layer and/or at transport layer. When the filing rate of such a data buffer is below a predefined threshold, the wireless transmitter TX **110** considers that the wireless receiver RX_1 **121**, RX_2 **122**, . . . , RX_{Ktot} **123** associated with said data buffer is not concerned by the frame to be transmitted. Thus, only the wireless receivers which data buffer filling rate is above a predefined threshold belong to the set of active wireless receivers ARX_1, ARX_2, . . . , ARX_K In a particular embodiment, in a manner complementary to the above approach, when the average data throughput on a given time window, which is typically much longer than a frame time duration, associated with a given wireless receiver is below a given threshold, said wireless receiver is considered as inactive.

In a step **S404**, the wireless transmitter TX **110** checks whether or not there is a change in the K active wireless receivers concerned by the frame to be transmitted compared with said preceding frame transmission. When the K active wireless receivers concerned by the frame to be transmitted are the same as previously, a step **S405** is performed; otherwise, the step **S407** is performed.

In a step **S405**, the wireless transmitter TX **110** determines whether long-term statistics, related to each one of the K active wireless receiver which was already present in the transmission system when said preceding frame transmission has occurred, have changed since said preceding frame transmission. As already mentioned, the long-term statistics are SINR and covariance matrices resulting from observations made by the active wireless receivers ARX_1, ARX_2, . . . , ARX_K over time during transmissions performed by the wireless transmitter TX **110**. Such long-term statistics are computed from noise power observed by the active wireless receivers ARX_1, ARX_2, . . . , ARX_K, and averaged wideband power observed by the active wireless receivers ARX_1, ARX_2, . . . , ARX_K from the wireless transmitter TX **110** and from any other interfering transmitter (such as another base station).

In a step **S406**, the wireless transmitter TX **110** checks whether or not the long-term statistics have changed. When the long-term statistics have changed, the step **S407** is performed; otherwise, a step **S408** is performed.

In the step **S407**, the wireless transmitter TX **110** considers that the receive conditions have changed compared with said preceding frame transmission, and thus the candidate combinations of concurrent beams shall be re-processed.

In the step **S408**, the wireless transmitter TX **110** considers that the receive conditions have not changed compared with said preceding frame transmission, and thus preceding candidate combinations of concurrent beams can be re-used.

FIG. **5** schematically represents an algorithm for determining the candidate combinations of concurrent beams which can be applied for transmitting a frame toward Np wireless receivers.

At this point, it is considered that the wireless transmitter TX **110** has identified the K wireless receivers that are supposed to be active in the transmission system for the frame transmission to be considered. The active wireless receivers ARX_1, ARX_2, . . . , ARX_K are indexed from 1 to K. The goal of the algorithm of FIG. **5** is to select Nc candidate combinations C(1), . . . , C(Nc) of concurrent beams built from Nb=Na candidate predefined beam configurations that can be concurrently used (i.e. combined) and that are stored in a codebook CB of the wireless transmitter TX **110**. Each candidate predefined beam configuration stored in the codebook CB corresponds to a specific phase pattern configuration of the analog precoder **204**. The selected Nc candidate combinations of concurrent beams are then further used as a basis for appropriately grouping the wireless receivers in the scheduling process, either in the first configuration phase or in the second configuration phase, as detailed hereafter.

One main challenge of MU-MIMO transmissions relates to group creation, i.e. deciding which wireless receivers should be grouped together on the same time and frequency resource(s). Indeed, dynamically building groups according to a fairness constraint usually requires too large scheduling processing complexity. Complexity is further increased by an additional degree of freedom provided by the variety of possible combinations of concurrent beams which can be selected for each frame transmission. Thus, it is proposed to semi-statically select the Nc candidate combinations C(1), . . . , C(Nc) of concurrent beams using the aforementioned long-term statistics, in a manner compliant with the fairness constraint.

In a step **S501**, the wireless transmitter TX **110** performs initialization. Initialization consists in assigning default values to temporary parameters used for determining the adequate candidate combinations of concurrent beams. In particular, an index Cidx is set to "1", and a theoretical average rate parameter Rav1(j) is set to "0", wherein j is an index such that $0<j<K+1$. Alternatively, the theoretical average rate parameter Rav1(j) is initialized with a value corresponding to the theoretical average rate achieved so far for the active wireless receiver ARX_1, ARX_2, . . . , ARX_K identified by the index j, or with a value corresponding to an effective total or average rate achieved so far for the active wireless receiver ARX_1, ARX_2, . . . , ARX_K identified by the index j, (see parameter Rav2(j) hereafter).

In a step **S502**, the wireless transmitter TX **110** obtains long-term statistics metric values for each one of the K wireless receivers active in the transmission system and for each one of the Nb candidate beam configurations stored in the codebook CB. The wireless transmitter TX **110** thus obtains a value of a metric of long-term transmission performance associated with transmission from the wireless transmitter TX **110** to each one of said K active wireless receivers ARX_1, ARX_2, . . . , ARX_K via each one of said Nb candidate beam configurations that can be used concurrently.

The long-term statistics metric is for example Shannon capacity $\log_2(1+SINR)$ based on long-term SINR computed from useful signal power received through the candidate beam configuration in question, and average interference power received from any potential interfering transmitter (such as neighboring base stations), and noise level. These power values are computed by the wireless receiver in question and periodically fed back to the wireless transmitter TX **110**. The data rate required for such a feedback has no significant impact on performance of transmissions from the wireless receiver in question since periodicity of feedback is in general large and corresponding amount of fed back data is rather low. Such a long-term statistics metric ignores intra-cell interference, i.e. the fact that other wireless receivers may be using beam configurations that may generate interference. Intra-cell interference can be managed by appropriately configuring the digital precoder **202** during the second configuration phase implemented by the online MU-MIMO fair scheduler. The long-term statistics metric may however take into account long-term intra-cell interference, as measured by the wireless receiver in question and fed back to wireless transmitter TX **110**. Such long-term intra-cell interference may then be added to inter-cell interference in order to refine SINR values.

In a variant, the long-term statistics metric values are for example extracted from a look-up table (LUT) providing association of system rate with long term SINR. Such a look-up table is pre-computed from different transmission modes including several modulation schemes, such as QAM schemes, and error correcting code rates.

In a step S**503**, the wireless transmitter TX **110** retains, as candidate combinations of concurrent beams, the combinations of concurrent beams which optimize a utility function (as known as figure of merit) of the offline MU-MIMO fair scheduler. The utility function of the offline MU-MIMO fair scheduler aims at taking into account by anticipation a fairness criterion intended to be applied in the scope of a utility function of the online MU-MIMO fair scheduler during the second configuration phase. The utility function of the offline MU-MIMO fair scheduler and the utility function of the online MU-MIMO fair scheduler diverge in that the utility function of the offline MU-MIMO fair scheduler uses the long-term statistics metric values to anticipate potential scheduling result, whereas the utility function of the online MU-MIMO fair scheduler uses effective channel conditions to decide scheduling to be effectively applied.

The offline MU-MIMO fair scheduler optimizes for example an alpha-fair criterion, which leads to the following utility function, wherein the Np beam configurations showing the best long-term statistics metric values have been retained beforehand for each wireless receiver:

$$\sum_{p=1}^{Np} \frac{UEBC(P(p, Cidx), U(p, Cidx))}{Rav1(U(p, Cidx))^{\alpha}}$$

wherein a is a fairness coefficient such that $-\infty<\alpha<+\infty$, wherein UEBC(P(p,Cidx), U(p,Cidx)) represents the long-term statistics metric value for the beam configuration identified by P(p, Cidx) and for the wireless receiver identified by U(p, Cidx). The denotation P(p, Cidx) shall be understood as an (absolute) identifier of the beam configuration represented by the value of the relative index p among the concurrent beams forming the combination of concurrent beams represented by the value of the index Cidx. In addition, the denotation U(p,Cidx) shall be understood as an (absolute) identifier of the wireless receiver associated with the beam configuration represented by the value of the relative index p among the concurrent beams forming the combination of concurrent beams represented by the value of the index Cidx.

One should note that the average rate parameter Rav1(j) is said to be "theoretical" since the offline MU-MIMO fair scheduler operates on estimations based on the long-term statistics metric values and not on effective CSI-data.

The result of the optimization provides the Nc candidate combinations C(1), . . . , C(Nc) of concurrent beams which provide the Nc best values (i.e. highest values, when relying on the utility function expressed above) of the utility function, in association with the Np wireless receivers among said K active wireless receivers ARX_1, ARX_2, . . . , ARX_K, as well as the Np corresponding respective concurrent beam configurations, which optimize the utility function.

In order to unambiguously identify the beam configurations used to build each combination of concurrent beams which have been indexed by the values of the index Cidx from 1 to Nc, the wireless transmitter TX **110** needs to retrieve beam configuration identifier values which are absolute among the Nb beam configurations stored in the codebook CB. Indeed, the index p identifies beam configurations only in a relative manner. The wireless transmitter TX **110** thus retrieves, for each candidate combination C(1), . . . , C(Nc) of concurrent beams, the effective beam configurations B(p, Cidx) used at each port p out of the Np concurrently used in said combination of concurrent beams. The denotation B(p,Cidx) shall be understood as an (absolute) identifier of the beam configuration, among the Nb beam configurations stored in the codebook CB, represented by the value of the relative index p among the concurrent beams forming the combination of concurrent beams represented by the value of the index Cidx. B(p, Cidx) is thus defined as follows:

$$B(p,Cidx)=UEBI(P(p,Cidx),U(p,Cidx))$$

wherein UEBI is an index mapping function such that UEBI(P(p,Cidx),U(p,Cidx)) represents the effective beam index (absolute index) among the Nb beam configurations stored in the codebook CB of the beam configuration P(p, Cidx) associated with the wireless receiver U(p, Cidx).

In a first approach, the optimization is performed by randomly selecting pairs of wireless receivers and beams configurations, and by retaining the Np ones providing the best result of the utility function.

In a second approach, the optimization is performed by executing the algorithm described hereafter with respect to FIG. **6**.

At the end of the algorithm of FIG. **5**, the wireless transmitter TX **110** ends the first configuration phase. The wireless transmitter TX **110** has thus selected the Nc candidate combinations C(1), . . . , C(Nc) of concurrent beams which can be used for performing the effective scheduling in the second configuration phase and corresponding transmission of at least one frame. It shall by the way be noted that the candidate combinations C(1), . . . , C(Nc) therefore consist of respective distinct sets of absolute identifiers B(p, Cidx) as defined above.

In a first embodiment, the Np wireless receivers supposed to be targeted with each one of the Nc candidate combinations C(1), . . . , C(Nc) of concurrent beams are defined by the offline MU-MIMO fair scheduler during the first configuration phase. In a second embodiment, the Np wireless receivers effectively addressed with any one of the Nc candidate combinations C(1), . . . , C(Nc) of concurrent beams are defined by the online MU-MIMO fair scheduler during the second configuration phase. More details are provided hereafter with respect to FIGS. **7** and **8**.

FIG. **6** schematically represents an algorithm for determining the candidate combinations of concurrent beams which can be applied for transmitting the frame toward the plurality of wireless receivers, in a particular embodiment. More particularly, the algorithm of FIG. **6** provides an exemplary detailed embodiment of the steps S**502** and S**503**. It is thus considered that, at the beginning of the algorithm of FIG. **6**, the initializing step S**501** has been performed beforehand.

In a step S**601**, the wireless transmitter TX **110** sorts, for each wireless receiver among the K active wireless receivers

ARX_1, ARX_2, . . . , ARX_K, the Nb beam configurations in performance-decreasing order of the long-term statistics metric values.

In a step **S602**, the wireless transmitter TX **110** retains, for each wireless receiver among the K active wireless receivers ARX_1, ARX_2, . . . , ARX_K, the top Np beam configurations as sorted in the step **S601**. It is indeed not needed here to consider more than Np beam configurations per wireless receiver, since Np represents the quantity of beams that can be used concurrently, which means that, in the worst case, any wireless receiver is supposed to be associated with its Np-th worst beam (among all possible concurrent beams described in the codebook CB). At that time, the wireless transmitter TX **110** builds the index mapping function UEBI.

In a step **S603**, the wireless transmitter TX **110** checks whether or not the value of the index Cidx is greater than Nc. It is reminded that the index Cidx has been initialized to "1" in the step **S501**. If the value of the index Cidx is greater than Nc, a step **S604** is performed; otherwise, a step **S605** is performed.

In the step **S604**, the wireless transmitter TX **110** retrieves, for each combination of concurrent beams which have been indexed by the values of the index Cidx from 1 to Nc, the effective beam configurations B(p, Cidx) used at each port p out of the Np concurrently used in said combination of concurrent beams. Indeed, since in the step **S602** only the top Np beam configurations have been retained for each wireless receiver, the index p identifies beam configurations in a relative manner. Therefore, the effective concurrent beams of each candidate combination C(1), . . . , C(Nc) shall be identified, in an absolute manner (thanks to the index mapping function UEBI( ) expressed above), so as to accurately define said candidate combination C(1), . . . , C(Nc) of concurrent beams and allow appropriately configuring later on the analog precoder **204** during frame transmissions. This ends the algorithm of FIG. **6**.

In the step **S605**, the wireless transmitter TX **110** sets the index p to "1".

In a step **S606**, the wireless transmitter TX **110** stores the long-term statistics metric values in a temporary parameter m'. In particular, the wireless transmitter TX **110** defines values m'(i,j) of the temporary parameter m' such that

$$m'(i,j)=UEBC(i,j),$$

with index i in range [1; Np] and index j in range [1; K].

In a step **S607**, the wireless transmitter TX **110** checks whether or not the index p is greater than Np. If the index p is greater than Np, a step **S608** is performed; otherwise, a step **S609** is performed.

In the step **S608**, the index Cidx is incremented by one unit. In other words, the wireless transmitter TX **110** moves to determining another candidate combination of concurrent beams. Then the step **S603** is repeated.

In the step **S609**, the wireless transmitter TX **110** selects the indexes couple (i',j') maximizing the expression $m'(i',j')/Rav1(j')^{\alpha}$ and store them as U(p, Cidx)=j' and P(p, Cidx)=i'. In other words, the wireless transmitter TX **110** stores a beam configuration that maximizes an average-rate-based alpha-fair utility function of the offline scheduler for the current values of the index p and the index Cidx.

In a step **S610**, the wireless transmitter TX **110** updates the average data rate Rav1(j') according to the result of the step **S609**. In other words, the wireless transmitter TX **110** adds m'(i',j') to the contents of Rav1(j') and stores the result in Rav1(j').

In a step **S611**, the wireless transmitter TX **110** resets (sets to a null value) the temporary parameter m'(i',j') for the indexes couple (i',j') selected in the step **S609**. Thus the concerned beam configuration cannot be attributed again to the same wireless receiver.

In a particular embodiment, the same beam configuration cannot be used twice at the same time. Thus, in the step **S611**, the wireless transmitter TX **110** further finds all the couples of indexes (i",j") such that UEBI(i",j")=UEBI(i',j') and resets (sets to a null value) the temporary parameter m'(i",j").

In another particular embodiment, the quantity of beam configurations that can be allocated to each wireless receiver is upper bounded. The upper bound is for example equal to the quantity of receive antennas of said wireless receiver. In this case, the wireless transmitter TX **110** ensures that the quantity of beam configurations associated with any wireless receiver does not exceed such a predefined upper bound for said wireless receiver. When said upper bound is reached, the wireless transmitter TX **110** resets the temporary parameter m' for said wireless receiver, so that no further beam configuration is selected for said wireless receiver in the candidate combination C(Cidx) under definition.

In a step **S612**, the wireless transmitter TX **110** increments by one unit the index p. In other words, the wireless transmitter TX **110** moves to determining another beam configuration that would be added to the on-the-way definition of the candidate combination identified by the value of the index Cidx. Then the step **S607** is repeated.

FIG. **7** schematically represents an algorithm for performing scheduling and transmitting a frame toward the concerned plurality of wireless receivers, in a first scheduling particular embodiment.

In a step **S701**, the wireless transmitter TX **110** detects that a frame has to be transmitted. This frame shall be processed by the online scheduler.

In a step **S702**, the wireless transmitter TX **110** sets the index Cidx to "1".

In a step **S703**, the wireless transmitter TX **110** checks whether or not the index Cidx is greater than Nc. When the index Cidx is greater than Nc, a step **S715** is performed; otherwise, a step **S704** is performed.

In the step **S704**, the wireless transmitter TX **110** sets the index p to "1".

In a step **S705**, the wireless transmitter TX **110** checks whether or not the index p is greater than Np. When the index p is greater than Np, a step **S706** is performed; otherwise, a step **S711** is performed.

In the step **S706**, the wireless transmitter TX **110** sets an index m to "1". The index m is used to identify any time and frequency resources among the M time and frequency resources to be used to transmit the frame.

In a step **S707**, the wireless transmitter TX **110** checks whether or not the value of the index m is greater than M. When the index m is greater than M, a step **S708** is performed; otherwise, a step **S709** is performed.

In the step **S708**, the wireless transmitter TX **110** increments the index p by one unit. In other words, the wireless transmitter TX **110** selects the next beam configuration of the candidate combination C(Cidx) of concurrent beams. Then the step **S705** is repeated.

In the step **S709**, the wireless transmitter TX **110** computes useful channels Hu(p,m) of the wireless receiver identified by U(p,Cidx) resulting from the CSIT-related data for the resource identified by the index m, by selecting the channels associated to the beam configuration identified by B(p,Cidx). Moreover, the wireless transmitter TX **110** computes interference channels Hi(p,m) of the wireless receiver identified by U(p,Cidx) resulting from the CSIT-related data, by selecting the channels associated to the beam configurations identified by B(1,Cidx), . . . , B(p−1,Cidx), B(p+1, Cidx), . . . , B(Np, Cidx), i.e. the beam configuration identified by B(p, Cidx) being excluded.

In the step **S710**, the wireless transmitter TX **110** increments the index m by one unit. In other words, the wireless transmitter TX **110** considers another time and frequency resource among the M time and frequency resources to be used to transmit the frame. Then the step **S707** is repeated.

In the step **S711**, the wireless transmitter TX **110** optionally computes M configurations of the digital precoder **202** (one configuration for each one of the M time and frequency resources to be used to transmit the frame), from the useful channels Hu(p,m) and interference channels Hi(p,m) computed over the successive iterations of the step **S709** for the candidate combination C(Cidx) of concurrent beams.

In a step **S712**, the wireless transmitter TX **110** computes, and stores, instantaneous rates r(p,Cidx,m) (which means the following set of instantaneous rates r(1,Cidx,m), . . . , r(Np,Cidx,m)) expected to be achieved for each one of the Np wireless receivers targeted by the frame over the time and frequency resource m, according to the useful channels Hu(p,m) and optionally to the precoder configurations computed in the step **S711**. The denotation r(p, Cidx,m) refers herein thus to the instantaneous rate expected to be achieved via the time and frequency resource m among the M time and frequency resources, for the wireless receiver identified by the value of the index p using the candidate combination C(Cidx) of concurrent beams. This instantaneous rate computation is performed for each time and frequency resource m among the M time and frequency resources.

In a step **S713**, the wireless transmitter TX **110** computes, and stores, values of the online utility function. The online MU-MIMO fair scheduler optimizes for example an alpha-fair criterion, which leads to the following utility function:

$$\sum_{p=1}^{Np} \frac{\sum_{m=1}^{M} r(p, Cidx, m)}{Rav2(U(p, Cidx))^{\alpha}}$$

wherein Rav2(i) is the effective total rate, or in a variant the effective average rate, achieved for the wireless receiver identified by the index value i from initialization of said total rate Rav2(i) or equivalently from the last re-initialization of said total rate Rav2(i). According to one example, said total rate Rav2(i) is reset when the wireless receiver in question becomes active again (after some period during which said wireless receiver has been inactive or considered as such). According to another example, said total rate Rav2(i) is initialized when the wireless receiver in question is declared in the transmission system (and becomes thus part of the Ktot wireless receivers of the transmission system). According to yet another example, said total rate Rav2(i) is reset periodically, so as to regularly refresh said total rate Rav2(i) and thus get rid of potential computation errors.

In a step **S714**, the wireless transmitter TX **110** increments the index Cidx by one unit. In other words, the wireless transmitter TX **110** selects another combination of concurrent beams among the candidate combinations C(1), . . . , C(Nc) of concurrent beams which were resulting from the first configuration phase implemented by the offline MU-MIMO fair scheduler. Then the step **S703** is repeated.

In the step **S715**, the wireless transmitter TX **110** performs scheduling so as to optimize the online utility function. The wireless transmitter TX **110** retains the candidate combination of concurrent beams among the candidate combinations C(1), . . . , C(Nc) which shows the best performance according to the online utility function.

In a step **S716**, the wireless transmitter TX **110** updates the rates Rav2(i) according to the scheduling decision made in the step **S715**. The wireless transmitter TX **110** retrieves the wireless receivers U(p, Cidx) for which data are transmitted in the frame in question and updates their respective rates Rav2 in accordance to the made scheduling decision. The other wireless receivers being not served by the frame in question, the wireless transmitter TX **110** updates their respective rates Rav2 in accordance (to take into account that the instantaneous rate for the non-served wireless receivers is null for the frame in question).

In a step **S717**, the wireless transmitter TX **110** configures itself according to the combination of beam configurations resulting from the step **S715** and transmits the frame over the M time and frequency resources accordingly.

In view of the algorithm of FIG. **7**, the same group of wireless receivers is selected for the whole band since the beam configurations identified by B(1,Cidx), . . . , B(Np,Cidx) and the wireless receivers identified by U(1, Cidx), . . . , U(Np, Cidx) are wideband. Thus, the online MU-MIMO fair scheduler is working in the time domain only, which limits flexibility of the scheduling process. Another approach is to not take into account the group of wireless receivers as proposed at the end of first configuration phase implemented by the offline MU-MIMO fair scheduler. This aspect is detailed with respect to FIG. **8** hereafter.

FIG. **8** schematically represents an algorithm for performing scheduling and transmitting frame toward the concerned plurality of wireless receivers, in a second scheduling particular embodiment.

In a step **S801**, the wireless transmitter TX **110** detects that a frame has to be transmitted. This frame shall be processed by the online scheduler.

In a step **S802**, the wireless transmitter TX **110** sets the index Cidx to "1".

In a step **S803**, the wireless transmitter TX **110** checks whether or not the index Cidx is greater than Nc. When the index Cidx is greater than Nc, a step **S813** is performed; otherwise, a step **S804** is performed.

In the step **S804**, the wireless transmitter TX **110** sets the index p to "1".

In a step **S805**, the wireless transmitter TX **110** checks whether or not the index p is greater than Np. When the index p is greater than Np, a step **S806** is performed; otherwise, a step **S811** is performed.

In the step **S806**, the wireless transmitter TX **110** sets an index m to "1". The index m is used to identify any time and frequency resources among the M time and frequency resources to be used to transmit the frame.

In a step **S807**, the wireless transmitter TX **110** checks whether or not the value of the index m is greater than M. When the index m is greater than M, a step **S808** is performed; otherwise, a step **S809** is performed.

In the step **S808**, the wireless transmitter TX **110** increments the index p by one unit. In other words, the wireless transmitter TX **110** selects the next beam configuration of the candidate combination C(Cidx) of concurrent beams. Then the step **S805** is repeated.

In the step **S809**, the wireless transmitter TX **110** computes useful channels Hu(p,m,1), . . . Hu(p,m,K) respectively of the K active wireless receivers ARX_1, ARX_2, . . . , ARX_K. Said useful channels result from the CSIT-related data for the time and frequency resource identified by the index m, by selecting the channels associated to the beam configuration identified by B(p, Cidx). Moreover, the wireless transmitter TX **110** computes interference channels Hi(p,m,1), . . . , Hi(p,m,K) of the K active wireless receivers. Said interference channels result also from the CSIT-related data, by selecting the channels associated with the beam configurations identified by B(1,Cidx), . . . , B(p−1, Cidx), B(p+1, Cidx), . . . , B(Np, Cidx). Comparatively with the step S**709**, the association between the beams configurations and the targeted wireless receivers is not fixed in the scope of the algorithm of FIG. **8** (contrary to the scope of the algorithm of FIG. **7**). This explains why the useful channels Hu(p,m,1), . . . Hu(p,m,K) and interference channels Hi(p, m,1), . . . , Hi(p,m,K) are determined here for each one of the K active wireless receivers ARX_1, ARX_2, . . . , ARX_K.

In the step S**810**, the wireless transmitter TX **110** increments the index m by one unit. In other words, the wireless transmitter TX **110** considers another time and frequency resource among the M time and frequency resources to be used to transmit the frame. Then the step S**807** is repeated.

In the step S**811**, the wireless transmitter TX **110** performs an online MU-MIMO scheduling estimation for the selected candidate combination C(Cidx) of concurrent beams. It is referred to online MU-MIMO scheduling "estimation" here, since no MU-MIMO scheduling decision is made in the step S**811**. Indeed, the wireless transmitter TX **110** performs optimization only for the selected candidate combination C(Cidx) of concurrent beams at this step. Decision about the candidate combination C(1), . . . , C(Nc) to be effectively used for transmitting the frame in question is made later on (see step S**813** below). It can consequently be considered in other words that the wireless transmitter TX **110** thus performs a Cidx-limited online MU-MIMO scheduling estimation.

The online MU-MIMO scheduling estimation takes as input the useful channels Hu(p,m,1), . . . Hu(p,m,K) and interference channels Hi(p,m,1), . . . , Hi(p,m,K) computed in the step S**809**. The online MU-MIMO scheduling estimation further takes as input the rate Rav2(i) for each one of the K active wireless receivers ARX_1, ARX_2, . . . , ARX_K, wherein Rav2(i) is (as already expressed with respect to FIG. **7**) the total rate, or in a variant the average rate, achieved for the wireless receiver identified by the index value i from initialization of said total rate Rav2(i) or equivalently from the last re-initialization of said total rate Rav2(i). According to one example, said total rate Rav2(i) is reset when the wireless receiver in question becomes active again (after some period during which said wireless receiver has been inactive or considered as such). According to another example, said total rate Rav2(i) is initialized when the wireless receiver in question is declared in the transmission system (and becomes thus part of the Ktot wireless receivers of the transmission system). According to yet another example, said total rate Rav2(i) is reset periodically, so as to regularly refresh said total rate Rav2(i) and thus get rid of potential computation errors.

The online MU-MIMO scheduling estimation gives as output a set of M sets of Np wireless receivers identified by U'(p, Cidx,1), . . . , U'(p, Cidx, M), which optimizes the online utility function. The denotation U'(p, Cidx,m), with m from 1 to M, shall be understood as an (absolute) identifier of the wireless receiver associated with the beam configuration represented by the value of the relative index p among the concurrent beams forming the combination C(Cidx) of concurrent beams when transmitting data over the time and frequency resource m among the M time and frequency resources to be used to transmit the frame in question.

The online MU-MIMO fair scheduler optimizes for example an alpha-fair criterion, which leads to the following utility function:

$$\sum_{p=1}^{Np}\sum_{m=1}^{M}\frac{r'(p, Cidx, m)}{Rav2(U'(p, Cidx, m))^{\alpha}}$$

where the denotation r'(p, Cidx, m) refers herein thus to the instantaneous rate expected to be achieved via the time and frequency resource m among the M time and frequency resources, for the wireless receiver identified by U'(p, Cidx, m) with the beam configuration B(p,Cidx). The wireless transmitter TX **110** takes into account rate improvement that can be achieved by the digital precoder **202** when present.

According to one example, the step S**811** is performed by exhaustively testing all possible sets of wireless receivers mapping to the Np beam configurations constituting the candidate combination C(Cidx) of concurrent beams via each one of the M time and frequency resources to be used for transmitting the frame in question. According to another example, the step S**811** is performed by using a random subset of all the possible sets of wireless receivers mapping to the Np beam configurations constituting the candidate combination C(Cidx) of concurrent beams via each one of the M time and frequency resources. According to yet another example, the step S**811** is performed by testing over the sets of groups of wireless receivers which were resulting from the offline MU-MIMO scheduler.

In a particular embodiment, the step S**811** is performed by defining, time and frequency resource after time and frequency resource (i.e. by performing optimization from time and frequency resource index going from 1 to M) which wireless receivers to be grouped together along with the adequate precoder configuration. For example, this can be achieved as disclosed in the document "*Simplified fair scheduling and antenna selection algorithms for multiuser MIMO orthogonal space-division multiplexing downlink*", Shreeram Sigdel and Witold A Krzymien, IEEE Transactions on Vehicular Technology, vol. 58, issue 3, pp. 1329-1344, March 2009.

Then, the wireless transmitter TX **110** stores the optimized value of the online utility function along with an identification of the wireless receivers U'(p, Cidx, m) targeted by the frame in question in view of the online MU-MIMO scheduling estimation for said candidate combination C(Cidx) of concurrent beams. The wireless transmitter TX **110** further stores the instantaneous rate r'(p, Cidx, m) that would be obtained for each one of said wireless receiver wireless receivers U'(p, Cidx, m) if said candidate combination C(Cidx) of concurrent beams is finally retained by the online MU-MIMO scheduler (see below).

In a step S**812**, the wireless transmitter TX **110** increments the index Cidx by one unit. In other words, the wireless transmitter TX **110** selects another combination of concurrent beams among the candidate combinations C(1), . . . , C(Nc) of concurrent beams which were resulting from the first configuration phase implemented by the offline MU-MIMO fair scheduler. Then the step S**803** is repeated.

In the step S**813**, the wireless transmitter TX **110** performs scheduling so as to optimize the online utility function. The wireless transmitter TX **110** retains the candidate combination C(1), . . . , C(Nc) of beam configurations which shows the best performance according to the online utility function.

In a step S**814**, the wireless transmitter TX **110** updates the rates Rav2(i) according to the scheduling decision made in the step S**813**. For each value of the index m from 1 to M, the wireless transmitter TX **110** retrieves the wireless receivers U'(p, Cidx, m) for which data are transmitted in the frame in question and updates their respective rates Rav2 in accordance to the made scheduling decision. The other wireless receivers being not served by the frame in question, the wireless transmitter TX **110** updates their respective rates Rav2 in accordance (to take into account that the instantaneous rate for the non-served wireless receivers is null for the frame in question).

In a step S**815**, the wireless transmitter TX **110** configures itself according to the combination of beam configurations resulting from the step S**813** and transmits the frame over the M time and frequency resources accordingly.

FIG. **9** schematically represents an algorithm for collecting channels observations. Indeed, knowledge by the wireless transmitter TX **110** of the MIMO channels observed by each wireless receiver is needed to build CSIT-related data. Typically, pilot signals are transmitted by the wireless transmitter TX **110**, thus allowing each wireless receiver to estimate MIMO channel characteristics.

In a step S**901**, the wireless transmitter TX **110** selects beam configurations to be used for transmitting the pilot signals toward the wireless receivers.

In practice, not all the MIMO channels need to be known by the wireless transmitter TX **110**. Indeed, by considering the candidate combinations C(1), . . . , C(Nc) of concurrent beams, it is highly probable that many of the Nb candidate beam configurations stored in the codebook CB are not present therein. Indeed, for a given spatial distribution of the wireless receivers, some places in the radio coverage area of the wireless transmitter TX **110**, and pointed by a given beam configuration, have no active wireless receiver among the active wireless receivers ARX_1, ARX_2, . . . , ARX_K. This involves that such a given beam configuration does not generate neither useful signal nor interference towards the active wireless receivers, and knowledge of corresponding MIMO channels is therefore non-necessary.

Thus, in a first option (inline with the algorithm of FIG. **7**), each candidate combination C(1), . . . , C(Nc) of concurrent beams is defined by the offline MU-MIMO scheduler in association with the wireless receivers to be targeted by said candidate combination of concurrent beams. In this case, all the possible MIMO channels for each candidate combination C(1), . . . , C(Nc) of concurrent beams are completely characterized. Thus, it is only required to send pilot signals for any beam configuration used in said candidate combinations C(1), . . . , C(Nc) of concurrent beams. This reduces the quantity of needed pilot signals, which either improves channel estimation or reduces overhead. A CSI feedback is thus obtained by the wireless transmitter TX **110** from the corresponding wireless receivers only on the MIMO channels characterized by the candidate combinations C(1), . . . , C(Nc) of concurrent beams.

Furthermore, two different candidate combinations C(1), . . . , C(Nc) of concurrent beams might have beam configurations in common, not necessarily targeting the same wireless receiver, but resulting in the same MIMO channel. Thus, in order to further limit CSI feedback in a particular embodiment, the wireless transmitter TX **110** determines the union of the beam configurations appearing in the different candidate combinations C(1), . . . , C(Nc) of concurrent beams and requests the wireless receivers to feedback CSI data related to said beam configurations of the union. Then the wireless transmitter TX **110** reassembles CSI-data related to said beam configurations in view of the candidate combinations C(1), . . . , C(Nc) of concurrent beams and is thus able to reconstruct the desired MIMO channels representations.

In a second option (inline with the algorithm of FIG. **8**), each candidate combination C(1), . . . , C(Nc) of concurrent beams is defined by the offline MU-MIMO scheduler in association with the wireless receivers to be optionally targeted by said candidate combination C(1), . . . , C(Nc) of concurrent beams from the standpoint of the offline MU-MIMO scheduler. It means that appropriately grouping the wireless receivers can be reviewed by the online MU-MIMO scheduler. In order to do so, and optionally to compute the appropriate digital precoder configuration, the wireless transmitter TX **110** needs to know all the potential MIMO channels that can be used. Thus, a CSI report is required by the wireless transmitter TX **110** from all the wireless receivers for all the beam configurations used in the candidate combinations C(1), . . . , C(Nc) of concurrent beams. Then the wireless transmitter TX **110** is able to reconstruct all the MIMO channels associated with any association of wireless receivers for each candidate combinations C(1), . . . , C(Nc) of concurrent beams.

In a step S**902**, the wireless transmitter TX **110** transmits pilot signals by using the beam configurations selected in the step S**901**.

In a step S**903**, the wireless transmitter TX **110** receives CSI-related data from the concerned wireless receivers.

As a remark, the wireless transmitter TX **110** obtains the CSI-related data for each time and frequency resource m among the M time and frequency resources used to transmit the frame in question by extrapolating the CSI-related data thus received from the wireless receivers.

FIG. **10** schematically represents an example hardware architecture of the wireless transmitter TX **110**. According to the shown example of hardware architecture, the wireless transmitter TX **110** comprises at least the following components interconnected by a communications bus **1010**: a processor, microprocessor, microcontroller or CPU (Central Processing Unit) **1001**; a RAM (Random-Access Memory) **1002**; a ROM (Read-Only Memory) **1003**; an HDD (Hard-Disk Drive) or an SD (Secure Digital) card reader **1004**, or any other device adapted to read information stored on non-transitory information storage medium; and a communication interface COM **1005**.

The communication interface COM **1005** enables the wireless transmitter TX **110** to transmit frames to the wireless receivers RX_1 **121**, RX_2 **122**, . . . , RX_{Ktot} **123** and to receive feedback information from the wireless receivers RX_1 **121**, RX_2 **122**, . . . , RX_{Ktot} **123**. The communication interface COM **1005** comprises the digital precoder **132**, the modulators **134**, the analog precoder **135** and the massive antennas set **136**.

CPU **1001** is capable of executing instructions loaded into RAM **1002** from ROM **1003** or from an external memory, such as an SD card via the SD card reader **1004**. After the wireless transmitter TX **110** has been powered on, CPU **1001** is capable of reading instructions from RAM **1002** and executing these instructions. The instructions form one computer program that causes CPU **1001** to perform some or all of the steps of the algorithms described hereafter.

Consequently, it is understood that any and all steps of the algorithm described herein may be implemented in software by execution of a set of instructions or program by a programmable computing machine, such as a PC (Personal Computer), a DSP (Digital Signal Processor) or a microcontroller; or else implemented in hardware by a machine or a dedicated chip or chipset, such as an FPGA (Field-Programmable Gate Array) or an ASIC (Application-Specific Integrated Circuit). In general terms, the wireless transmitter TX **110** comprises processing electronics circuitry configured for implementing the relevant steps as described herein.

The invention claimed is:

1. A method for configuring a wireless transmitter comprising a massive transmit antennas arrangement, a set of modulators and an analog precoder mixing modulated analog signals output by the set of modulators onto respective inputs of the massive transmit antennas arrangement, the wireless transmitter further comprising a codebook storing candidate predefined beam configurations corresponding to a specific phase pattern configuration of the analog precoder, transmissions of frames by the wireless transmitter being performed onto respective M time and frequency resources by using combinations of concurrent beam configurations among the candidate predefined beam configurations stored in the codebook so as to perform Multi-User Multiple-Inputs Multiple-Outputs MU-MIMO transmissions toward wireless receivers, the method being implemented by the wireless transmitter,

wherein the wireless transmitter further comprises an MU-MIMO fair scheduler, referred to as online MU-MIMO fair scheduler, determining which combinations of concurrent beams to be applied onto the M time and frequency resources so as to take into account a fairness constraint between the wireless receivers in view of effective channel conditions toward the wireless receivers, wherein the wireless transmitter performs a frame transmission onto the M time and frequency resources by configuring the analog precoder according to the combinations of concurrent beams determined by the online fair scheduler,

wherein the wireless transmitter further comprises another MU-MIMO fair scheduler, referred to as offline MU-MIMO fair scheduler, implementing a first configuration phase in which the offline MU-MIMO fair scheduler determines candidate combinations of concurrent beams by using long-term statistics associated to performance of transmissions from the wireless transmitter toward the wireless receivers and by taking into account the fairness constraint between the wireless receivers,

wherein the online fair scheduler implements a second configuration phase in which the online MU-MIMO fair scheduler selects the combinations of concurrent beams to be applied onto the M time and frequency resources among the candidate combinations of concurrent beams determined by the offline MU-MIMO fair scheduler during the first configuration phase,

wherein the wireless receivers effectively targeted with any one of the candidate combinations of concurrent beams are defined by the online MU-MIMO fair scheduler during the second configuration phase,

wherein the offline MU-MIMO fair scheduler optimizes an alpha-fair criterion, which leads to the following utility function, where the Np beam configurations showing the best long-term statistics metric values have been retained beforehand for each wireless receiver:

$$\sum_{p=1}^{Np} \frac{UEBC(P(p, Cidx), U(p, Cidx))}{Rav1(U(p, Cidx))^{\alpha}}$$

where Rav1 (U(p, Cidx)) is a theoretical achievable total or average rate for the wireless receiver identified by U(p,Cidx) in view of long-term statistics, α is a fairness coefficient such that $-\infty<\alpha<+\infty$, UEBC(P(p,Cidx), U(p, Cidx)) represents the long-term statistics metric value for the beam configuration identified by P(p,Cidx) and for the wireless receiver identified by U(p,Cidx), further where P(p,Cidx) is an absolute identifier of the beam configuration represented by the value of the relative index p among the concurrent beams forming the combination of concurrent beams represented by the value of the index Cidx, and U(p,Cidx) is an absolute identifier of the wireless receiver associated with the beam configuration represented by the value of the relative index p among the concurrent beams forming the combination of concurrent beams represented by the value of the index Cidx,

and wherein the online MU-MIMO fair scheduler optimizes the alpha-fair criterion, which leads to the following utility function:

$$\sum_{p=1}^{Np} \sum_{m=1}^{M} \frac{r'(p, Cidx, m)}{Rav2(U'(p, Cidx, m))^{\alpha}}$$

where Rav2 (U'(p, Cidx,m)) is a total or average rate achieved for the wireless receiver identified by U'(p, Cidx, m) via a m time and frequency resource among the M time and frequency resources, and further where r'(p, Cidx, m) is instantaneous rate expected to be achieved via a m time and frequency resource for the wireless receiver identified by U'(p, Cidx, m) with the beam configuration B(p,Cidx).

2. The method according to claim **1**, wherein the wireless transmitter reinitiates the first configuration phase when receive conditions of the MU-MIMO transmissions have changed compared with a preceding frame transmission.

3. The method according to claim **2**, wherein the receive conditions of the MU-MIMO transmissions have changed compared with a preceding frame transmission when at least one of the following conditions is faced:

when the long-term statistics of at least one wireless receiver have changed since the preceding frame transmission;

when the wireless transmitter has not enough data anymore to be transmitted to at least one wireless receiver since the preceding frame transmission;

when the wireless transmitter has received new data to be transmitted to at least one wireless receiver for which there was precedingly not enough data to be transmitted thereto for the preceding frame transmission;

when there is a change, since the preceding frame transmission, in the wireless receivers that are active among all the wireless receivers of a transmission system to which the wireless transmitter belongs; and

when there is a change, since the preceding frame transmission, in presence of the wireless receivers in the transmission system.

4. The method according to claim **1**, wherein the wireless transmitter further comprises a digital precoder placed upstream the set of modulators, and the online MU-MIMO fair scheduler determines and further applies configurations of the digital precoder during the second configuration phase, namely one configuration of the digital precoder for each one of the time and frequency resources.

5. The method according to claim **1**, wherein the wireless transmitter determines the union of the beam configurations appearing in the candidate combinations of concurrent beams and requests the wireless receivers to feedback Channel State Information data related to said beam configurations of the union so as to determine the effective channel conditions toward the wireless receivers.

6. A non-transitory information storage medium storing a computer program comprising program code instructions that can be loaded in a programmable device for implementing the method according to claim **1**, when the program code instructions are run by the programmable device.

7. A wireless transmitter comprising a massive transmit antennas arrangement, a set of modulators and an analog precoder mixing modulated analog signals output by the set of modulators onto respective inputs of the massive transmit antennas arrangement, the wireless transmitter further comprising a codebook storing candidate predefined beam configurations corresponding to a specific phase pattern configuration of the analog precoder, transmissions of frames by the wireless transmitter being performed onto respective M time and frequency resources by using combinations of concurrent beam configurations among the candidate predefined beam configurations stored in the codebook so as to perform Multi-User Multiple-Inputs Multiple-Outputs MU-MIMO transmissions toward wireless receivers,

wherein the wireless transmitter further comprises an MU-MIMO fair scheduler, referred to as online MU-MIMO fair scheduler, determining which combinations of concurrent beams to be applied onto the M time and frequency resources so as to take into account a fairness constraint between the wireless receivers in view of effective channel conditions toward the wireless receivers, wherein the wireless transmitter further comprises means for performing a frame transmission onto the M time and frequency resources by configuring the analog precoder according to the combinations of concurrent beams determined by the online fair scheduler,

wherein the wireless transmitter further comprises another MU-MIMO fair scheduler, referred to as offline MU-MIMO fair scheduler, implementing a first configuration phase in which the offline MU-MIMO fair scheduler is configured to determine candidate combinations of concurrent beams by using long-term statistics associated to performance of transmissions from the wireless transmitter toward the wireless receivers and by taking into account the fairness constraint between the wireless receivers,

wherein the online fair scheduler implements a second configuration phase in which the online MU-MIMO fair scheduler is configured to select the combinations of concurrent beams to be applied onto the M time and frequency resources among the candidate combinations of concurrent beams determined by the offline MU-MIMO fair scheduler during the first configuration phase,

wherein the wireless receivers effectively targeted with any one of the candidate combinations of concurrent beams are defined by the online MU-MIMO fair scheduler during the second configuration phase,

wherein the offline MU-MIMO fair scheduler optimizes an alpha-fair criterion, which leads to the following utility function, where the Np beam configurations showing the best long-term statistics metric values have been retained beforehand for each wireless receiver:

$$\sum_{p=1}^{Np} \frac{UEBC(P(p, Cidx), U(p, Cidx))}{Rav1(U(p, Cidx))^{\alpha}}$$

where Rav1 (U(p, Cidx)) is a theoretical achievable total or average rate for the wireless receiver identified by U(p,Cidx) in view of long-term statistics, a is a fairness coefficient such that $-\infty<\alpha<+\infty$, UEBC(P(p,Cidx), U(p, Cidx)) represents the long-term statistics metric value for the beam configuration identified by P(p,Cidx) and for the wireless receiver identified by U(p,Cidx), further where P(p,Cidx) is an absolute identifier of the beam configuration represented by the value of the relative index p among the concurrent beams forming the combination of concurrent beams represented by the value of the index Cidx, and U(p,Cidx) is an absolute identifier of the wireless receiver associated with the beam configuration represented by the value of the relative index p among the concurrent beams forming the combination of concurrent beams represented by the value of the index Cidx,

and wherein the online MU-MIMO fair scheduler optimizes the alpha-fair criterion, which leads to the following utility function:

$$\sum_{p=1}^{Np} \sum_{m=1}^{M} \frac{r'(p, Cidx, m)}{Rav2(U'(p, Cidx, m))^{\alpha}}$$

where Rav2 (U'(p, Cidx,m)) is a total or average rate achieved for the wireless receiver identified by U'(p, Cidx, m) via a m time and frequency resource among the M time and frequency resources, and further where r'(p, Cidx, m) is instantaneous rate expected to be achieved via the m time and frequency resource for the wireless receiver identified by U'(p, Cidx, m) with the beam configuration B(p,Cidx).

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